ELSEVIER

Injury, Int. J. Care Injured 31 (2000) 609–612

INJURY
INTERNATIONAL JOURNAL OF THE CARE OF THE INJURED

www.elsevier.com/locate/injury

Ultrasound assessment of the vulnerability of the internal organs to stabbing: determining safety standards for stab-resistant body armour

Anthony Bleetman*, Jules Dyer

Birmingham Heartlands Hospital, Accident and Emergency Medicine, Bordesley Green East, Birmingham B9 5SS, UK

Accepted 10 April 2000

Abstract

Stab-resistant body armour may not always prevent the passage of a blade into the human body. The depth to which a knife may 'safely' enter the human body before it breaches the internal organs was explored by ultrasound scanning of 25 healthy volunteers. Variations in the minimum skin-to-organ distances for the organs as a function of posture are described. To determine the optimum body coverage by stab-resistant armour, the movement during the breathing cycle and the maximum exposure of the organs beneath the lower costal margin at full inspiration were measured. Although the population studied was small, trends in the vulnerability of the internal organs to the passage of a blade into the body were identified. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Ideal stab-resistant body armour would prevent edged weapons from penetrating the human body in stab attacks. With current materials, this cannot be guaranteed for all types of knife blades; some penetration into the body may occur before the passage of the knife can be arrested by the armour.

It is assumed that no serious injury to the victim will occur if the internal organs are not breached by the assailant's weapon. The 'safe' distance to which an assailant's knife can be pushed into the body before breaching the internal organs needs to be determined. A previous CT study has determined this distance for the internal organs in hospital patients lying supine in a scanner, with their arms above the heads [1]. The information from this study provided the basis for determining the new Home Office standard for issuing stab-resistant body armour to the Police [2]. To learn more about the vulnerability of organs to the passage of a blade into the body in different and more natural body postures, and at different stages of the breathing cycle, a dynamic ultrasound study was performed on healthy volunteers.

2. Methods

Twenty-five healthy volunteers aged between 18 and 50 were recruited. Ultrasound measurements of the minimum skin-to-organ distances were recorded for each subject in three postures: lying supine, standing erect, and leaning forward at 45° (braced against the examination couch). Each subject's height and weight were recorded.

All subjects were scanned with a Toshiba 3.75 MHz ultrasound curved strip probe measuring 1.75 × 7.5 cm. The probe was applied with a moderately firm pressure by the same operator.

The minimum distances to the kidneys, spleen and pericardium were measured, and the minimum depth of the pleura and liver (both anteriorly and lateraly) were measured during normal respiration.

In the erect position, organ movement with normal respiration was measured in the sagittal plane.

* Corresponding author.

PII: S0020-1383(00)00061-9

To determine the amount of exposure of each organ below the ribs, the distance of the lower pole of these organs from the lower costal margin at full inspiration was measured.

Measurements for the stomach and bowel were not recorded, as their mobility and variable distension would produce inconsistent data.

3. Results

3.1. Minimum skin-to-organ distances

The minimum skin-to-organ distances as a function of posture are presented in Fig. 1. The spleen was the shallowest organ and was only 9 mm deep to the skin in one subject in the supine position. The deepest organ was the right kidney, which was 56 mm deep to the skin in another subject, also in the supine position. There was no demonstrable difference in the skin-to-organ distances between male and female subjects.

The effect of posture on the minimum skin-to-organ distances is seen in Fig. 2. The internal organs were less accessible with subjects standing erect and leaning forward, with the exception of the anterior pleura in the erect position and the right kidney in the 45° leaning position in two subjects.

The movement of the organs in the sagittal plane during normal breathing is presented in Fig. 3. With the exception of the spleen in one subject, and the lateral aspect of the liver in another, the organs descended during inspiration in the normal breathing cycle.

The distance of the lower pole of the organs from the lower costal margin at full inspiration (the amount of organ exposed beneath the ribs) is presented in Fig. 4. The most vulnerable organ in terms of exposure beneath the lower rib margin was the lateral aspect of the liver in one subject descended to 165 mm at full inspiration.

The influence of Body Mass Index and gender on organ movement could not be determined, as the sample size was too small.

4. Discussion

Ideal stab-resistant body armour would prevent edged weapons from penetrating the human body in stab attacks, and would be light enough not to inter-

		Male n= 15		Female n=10		All n=25		
Organ	Posture	Minimum	Average	Minimum	Average	Minimum	Average	Maximum
Left kidney	Supine	13	29	13	28	13	28	48
	Erect	18	34	12	26	12	31	50
	45 degrees	15	29	13	27	13	28	49
Right kidney	Supine	17	32	17	28	17	31	56
	Erect	15	33	14	32	14	33	54
	45 degrees	14	27	16	26	14	27	40
Spleen	Supine	12	16	9	17	9	16	23
	Erect	17	21	13	22	13	22	33
	45 degrees	15	20	11	21	11	20	32
Liver ant.	Supine	10	18	10	19	10	18	27
	Erect	11	20	10	23	10	21	39
	45 degrees	13	22	12	20	12	21	31
Liver lat.	Supine	14	17	11	17	11	17	22
	Erect	17	21	11	23	11	22	37
	45 degrees	16	20	15	20	15	20	27
Pericardium	Supine	14	22	17	22	14	22	34
	Erect	15	25	12	25	12	25	41
	45 degrees	12	23	15	23	12	23	39
Pleura ant.	Supine	15	19	10	17	10	18	26
	Erect	10	18	10	15	10	17	23
	45 degrees	12	21	10	18	10	19	28
Pleura lat.	Supine	15	21	10	20	10	21	32
	Erect	16	22	10	22	10	22	35
	45 degrees	15	21	10	20	10	21	32

Fig. 1. Skin-to-organ distances as a function of posture.

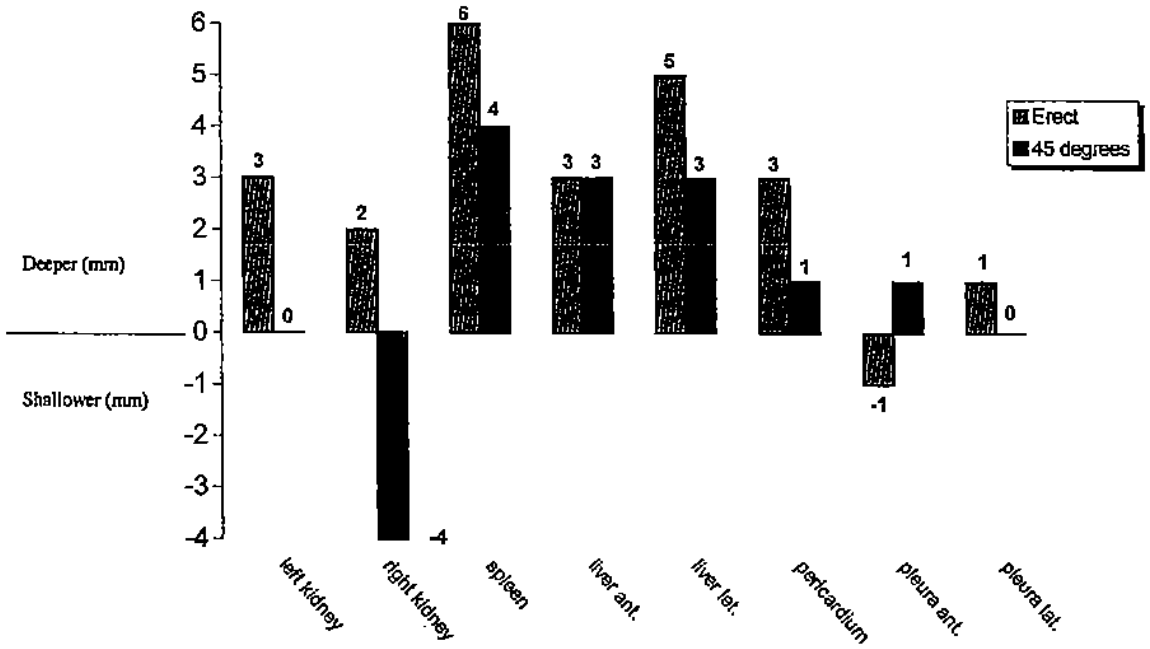

Fig. 2. The change in the average skin-to-organ depth for subjects moving from the supine position to the erect and 45° forward positions.

fere unduly with the wearer's ability to function. Armour designers need to carefully balance the 'wearability' against protection. With current materials, wearable armour cannot be guaranteed to prevent blade penetration into the human body for all types of knife blades; some penetration into the body may occur before the passage of the knife can be arrested by the armour.

Serious injury is most unlikely to occur if the assailant's knife fails to penetrate the internal organs, even if the blade breaches overlying soft tissue. In a previous CT study, the minimum skin-to-

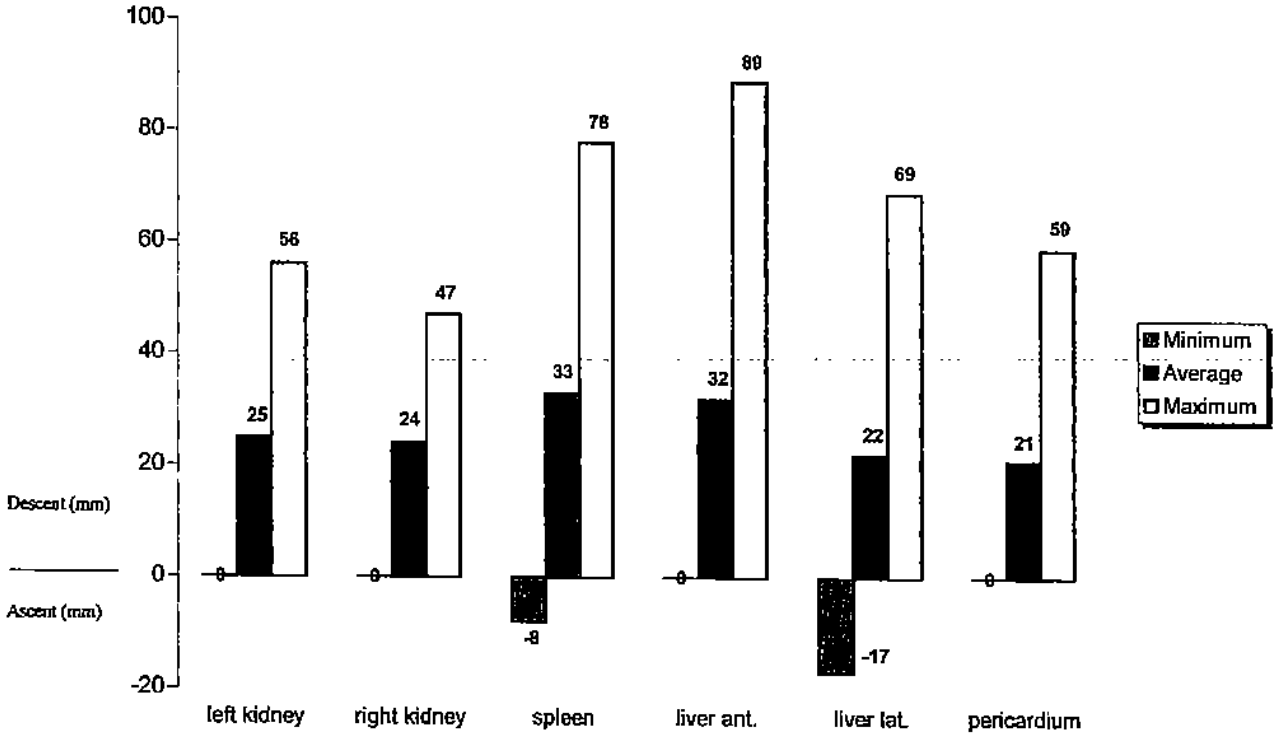

Fig. 3. Movement of the lower poles of the internal organs during normal breathing in the erect position.

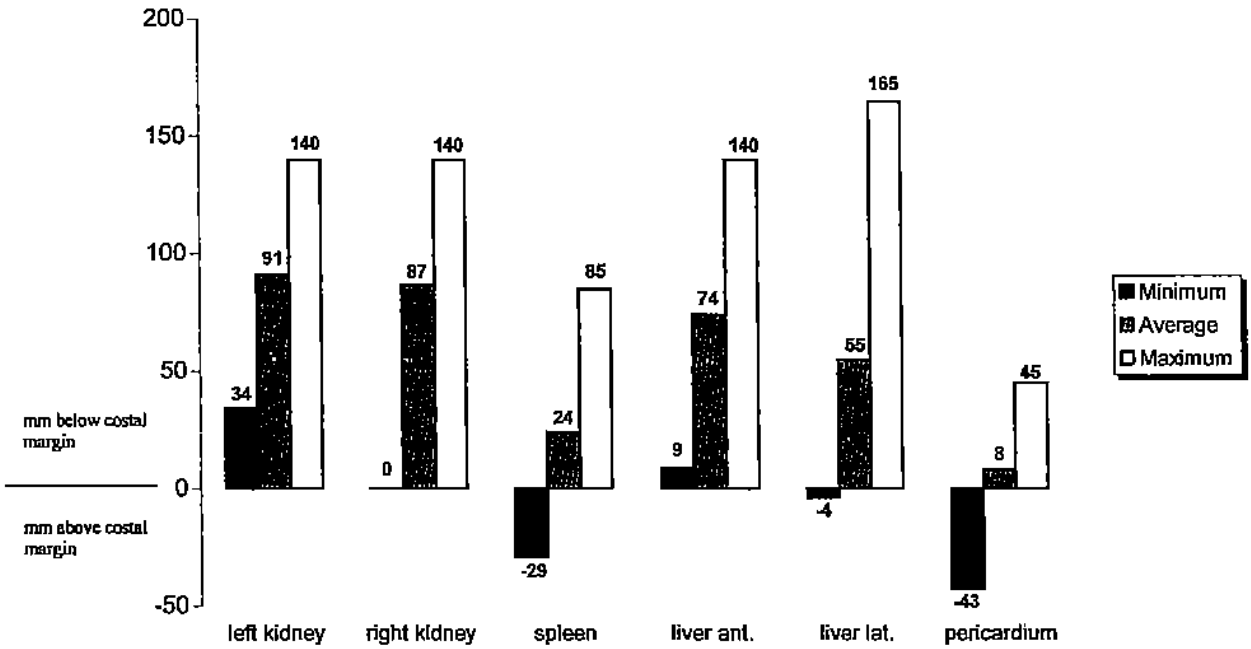

Fig. 4. Length of the exposed parts of the organs beneath the lower costal margin at full inspiration in the erect position.

organ distances were measured for 71 subjects. These subjects were hospital patients scanned in a supine position with their arms above the heads [1]. This study provided information on the accessibility of the internal organs; the most vulnerable organ was found to be the liver, which was only 9 mm deep to the skin in one individual. Subjects in this study were hospital patients lying in an abnormal posture for the purpose of scanning. To acquire more meaningful data, a more dynamic study on healthy individuals was required.

In this study, ultrasound scanning was used to learn more about the vulnerability of organs to the passage of a blade into the body in different body postures, and at different stages of the breathing cycle. Although there were only 25 subjects in this study, some trends in organ vulnerability became evident. The accessibility of the organs was determined by measuring the nearest part of the organ in three body postures and as a function of the breathing cycle. The lowest part of each organ at full inspiration in the erect position was also determined.

The minimum skin-to-organ distances measured in this study were very similar to those in the CT study: the most accessible organs lie only 9 mm beneath the skin in the thinnest individuals. The Home Office have accepted these findings in the new specification for issuing body armour to the Police [2]. Home Office approved body armour for Police officers must arrest a blade delivered at specified energies within 7 mm of its inner surface (the 9 mm limit was reduced to 7 mm to allow for 99% confidence levels).

With exceptions in two subjects, the organs were less accessible (deeper) in both the erect and the 45° leaning forward positions. This is presumably due to the effect of gravity on both the organs and the body wall, and perhaps also due to changes in muscular tension.

To be effective, armour must cover the most vulnerable organs. No previous work identifying the minimum area of required body coverage by armour has been identified. With the ultrasound measurements in this study, the degree of sagittal movement of the internal organs during normal breathing has been described (Fig. 3).

Knowledge of the accessibility of the organs as a function of both posture and breathing cycle will allow designers to determine the minimum margins of the armour, so that it covers and protects the most vulnerable organs in the lightest and most wearable protective garment.

Using this information, thresholds for defining high, medium and low risk areas of the human trunk need to be determined, and body armour designed to cover these areas to the appropriate degree of protection.

References

[1] Connor SEJ, Bleetman A, Duddy MJ. Safety standards for stab-resistant body armour; a computer tomographic assessment of organ to skin distances. Injury 1998;29(4):297–9.

[2] Stab-resistant body armour test procedure. Police Scientific Development Branch, Home Office Police Department, 1999.